Applications of Tree Growth Modelling in Decision Support for Sustainable Forest Management

HANS PRETZSCH[1], HEINZ UTSCHIG[2], RAINER SODTKE[3]

Abstract. Multi-functional silviculture and sustainable forest management in Europe was recently defined by the Helsinki Resolution H1 (MCPFE 1993). Sustainable development (SD) is associated with abandoning the concept of even-aged forests. In view of this extended SD perception, the conventional forest planning procedure has to be revised. By relying on yield tables and the model of normative forests at the overall enterprise planning level, the conventional results become increasingly irrelevant in forest management. Such outdated planning tools do not provide the information needed for multi-criteria strategic planning. Modern strategic forest planning and decision-making require appropriate tools and technologies, such as forest growth simulators, evaluation and optimisation algorithms, geographical information systems, sample-plot data and visualisation routines, most of which are supplied by forest growth and yield science. The main aspect is to combine these tools and integrate them into decision support systems supporting the planning and decision processes at the enterprise level. In particular, the application of forest growth simulators will enable an improved SD evaluation and a more flexible adjustment between single stand and total estate planning. Simulation models can replace common indicators with aggregated dynamic long-term indicators. Management alternatives can be analysed with regard to their estate-referring and long-term consequences. In this chapter, we will point out: (1) how forest planning and decision-making can evolve from monitoring forest development to strategic planning, (2) how the Pan-European criteria can be used for monitoring and strategic planning of SD at estate level, (3) how available forest planning data can be best utilised for the planning process, and (4) what could be contributed by forest growth and yield science to developing decision support systems for multi-criteria forest enterprise planning.

[1,2] Chair of Forest Yield Science, Technische Universität München, Am Hochanger 13, 85354 Freising, Germany
[3] Research Centre of Biotechnology, Society and Environment, University of Hamburg, Ohnhorststr. 18, 22609 Hamburg, Germany

Hubert Hasenauer (Ed.)
Sustainable Forest Management
Growth Models for Europe

7.1
Introduction

For almost 300 years, ordinary forestry has been arranged according to the demands of sustainability (e.g. von Carlowitz 1713; Hundeshagen 1826). The modern perception of multi-functional silviculture is reflected in the Helsinki Resolution H1 (MCPFE 1993, p. 1), in which sustainable forest management is defined as: "The stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems". The six Pan-European criteria and indicators of sustainable forest management (Table 7.1) negotiated at the Lisbon Resolution L2 should support the coverage of sustainability and their operational implementation (MCPFE 1993). In view of this extended perception of sustainable development (SD), which is associated with abandoning the concept of even-aged forests, the conventional procedure of forest planning has to be revised (Hanewinkel 2001; Spellmann et al. 2001; von Gadow 2003). Increasingly, its usefulness is restricted by: (1) deficient flexibility in terms of strategic planning, (2) a limited applicability for uneven-aged forests and variable management procedures, and (3) insufficient integration of those silvicultural functions that exceed timber production. Using yield tables and the model of normative forests to measure forest growth at the overall enterprise planning level is becoming increasingly outdated. These planning tools do not provide the information needed for multi-criteria planning. On the other

Table 7.1. Pan-European criteria 1–6 and corresponding indicators for sustainable forest development. (Adapted from MCPFE 1993)

Criteria	Indicators (examples)
1 Forest resources	Forest area, carbon storage, age and volume structure, ...
2 Forest ecosystem health and vitality	Chemical soil state, defoliation, deposition of nutrients/pollutants, ...
3 Productive functions	Growth, felling budget, non-wood products, ...
4 Biological diversity	Tree species diversity, orientation by nature, share of dead wood, landscape diversity, ...
5 Protective functions	Share of forest area for protection of climate, soil, water, ...
6 Socio-economic functions	Net financial yield, number of employees, natural scenery, ...

hand, apart from sample plots, site classification, etc., information is available that is barely utilised by the conventional forest planning procedure.

Modern strategic forest planning and decision-making require appropriate tools and technologies partially supplied by forest growth and yield science. For us, the main aspect is to combine the forest growth simulators with evaluation and optimisation algorithms, geographical information systems, sample-plot data or visualisation routines and integrate them into decision support systems supporting the planning and decision processes at the enterprise level. Applications of these methods and technologies – and dealing with the problems in the planning process – give transparency to the decision pathways, enable participation and negotiation with politicians and therefore pave the way for a strategic goal-orientated forest enterprise management.

This chapter highlights how forest planning and decision-making may evolve from monitoring forest development to strategic planning, how the Pan-European criteria can be used for monitoring and strategic planning of SD at estate level, how available forest planning data might be best utilised for the planning process, and what can be contributed by forest growth and yield science to developing decision support systems for multi-criteria forest enterprise planning.

7.2
Setting the Stage – Decision Support Systems and Tree Growth Models for Strategic Forest Enterprise Planning

7.2.1
Decision Support Systems

Strategic forest enterprise planning due to multiple planning objectives is a typical field of application for decision support systems (DSS) with many complex and unstructured problems (Bonczek et al. 1981). A DSS to support such planning decisions can be structured according to the theory of a rational objective-orientated decision (Bamberg and Coenenberg 2002). Therefore, it will be designed to evaluate a set of different management alternatives as well as integrating multiple planning objectives, by the fulfilment of which the management alternatives will be assessed (Sodtke 2003). DSS are defined as systems utilising data and modularly integrating several models and methodical components for the different tasks of problem solution and decision-making (e.g. Turban 1990; Janssen 1992; Rauscher 1999). Many tools and technologies are available to support decision-making at estate level, most of which are supplied by forest yield and growth science. Examples include forest growth simulators, forest inventory databases, geographical information systems (GIS), visualisation systems and evaluation and optimisation algorithms (Sodtke et al. 2004). Forest growth simulators serve for running scenario simulations, for analysing the long-term consequences of management alternatives, and for scaling the results at different spatial and temporal levels. GIS and visualisation routines illustrate these consequences on stand and landscape dynamics and pave the way for participative planning. With the use of evaluation models, simulation results can be structured, evaluated and passed on to the decision process: different planners' objectives and priorities leading to differing valuations of the same states and management actions can be revealed, and multi-criteria functional and sensitivity analyses can be conducted. All these tools should be combined to form comprehensive DSS for the purposes of strategic forest enterprise planning.

7.2.2

Enterprise Simulation as the Backbone of Strategic Planning

Simulation models promise an improved evaluation of SD and a more flexible adjustment between single stand and total estate planning. In the case of a particular objective, they may support identifying the optimum management alternative. Provided that growth models are applicable for stands of diverse mixture and age structure as well as for simulating realistic growth dynamics for a wide range of management alternatives, they might replace the common area-specific or volume-specific indicators for measuring the annual felling volume. These indicators lose significance in abandoning the concept of even-aged forests; equation-based indicators do so when measured growth rates deviate from expected values of yield tables. In contrast, simulation runs with growth models may replace common indicators in aggregating long-term growth dynamics caused by defined management strategies at stand and stratum level and transfer them to estate level. Models directly return long-term dynamics of growing stock, increment, property value, financial return, structural indices, diversity of tree species, etc. SD indicators based on the model of normative forests or yield tables become redundant.

The advantage of enterprise simulation runs performed by growth models in fact lies in its improved planning flexibility: undesired dynamics at estate level can be identified and corrected by a changed planning procedure at stand or estate level. The recursive procedure Speidel (1972, p. 162) strives for – "corrections are repeated as long as a convenient adjustment between singular and total planning is attained" – has proven to be elaborate, laboured and barely feasible with planning of sustainable timber production in even-aged forests. In uneven-aged forests with a wider range of management models and SD criteria, a recursive procedure is only possible with support of simulation models.

7.3
From Monitoring Forest Development to Strategic Planning

7.3.1
Monitoring

The criteria verifying sustainable forest development – negotiated at the European level (MCPFE 1993) –are characterised quantitatively by associated indicators aiming at a practical application from forest enterprise to the national level (Spellmann 2003). Indicators such as diversity of tree species, orientation by nature, proportion of dead wood within the standing or lying stock, and vertical stand structure have to be deduced from forest inventories. They can, for example, be used to determine the criterion 'biodiversity'.

For deriving indicators and determining the catalogue of criteria, a large variety of sources of information are available. For this, inventories of forest enterprise planning, constant ecological monitoring plots, maps of soil and site characteristics, and immission load maps are very revealing sources. Having collected this information, a multi-criteria impression of forest enterprise development evolves. For example, previous development can be compared with the enterprise's planning objectives. With this procedure – among others – objective fulfilment, erroneous trends and necessary corrections can be readily identified. However, criteria and indicators derived with such an application are restricted to information, data and knowledge that already exists.

Let us assume that forest development within the period $[t_0, t_m]$ according to a referred site unit (e.g. stand, stratum, estate, growth region, state) is characterised by the indicators $[I_1, ..., I_n]$ (cf. Fig. 7.1). Let indicators $[I_1, ..., I_n]$ be growing stock, volume increment, net financial yield, diversity, protective functions, etc. If this forest evolves to the states $[W_1, ..., W_n]$ the development may be documented by repeated measures of the aforementioned indicators (by inventories, random sampling, visual valuation) at the points in time $[t_0, t_m]$. The dynamic states

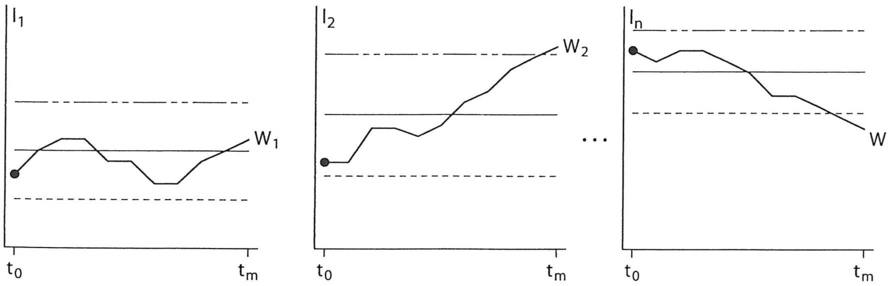

Fig. 7.1. Application of the indicators $[I_1, ..., I_n]$ for multi-criteria forest monitoring in the time span t_0 to t_m. *Solid lines* represent the target value of the indicator; *broken lines* show the critical levels

$[W_1,...,W_n]$ can be compared with fixed target values, e.g. for tree species composition, growing stock, return on financial investment (cf. Fig. 7.1, solid lines). Furthermore, it will be evident whether observed dynamics evolve within a predefined target corridor, e.g. between specific limits for felling volume, financial yield, liquidity, critical levels for deposition or emission rates (cf. Fig. 7.1, dashed lines).

In our example (Fig. 7.1) at the initial point in time to (black circle), indicator I_1 deviates slightly from the target value but remains within the desired corridor the whole time. On the other hand, I_2 (e.g. growing stock) evolves in a totally undesired way. Indicator I_n (e.g. structural diversity) at first evolves in a target-orientated manner, but then converges to the lower limit and falls below it. The wider the topical range of the indicators $[I_1, ..., I_2]$, the more comprehensively the dynamics can be reported, and the more criteria can be integrated for erroneous trends to be made obvious and demands for corrections to be made evident. The potential demand for corrections depends on the weighting of the particular criteria. The weighting results from the predefined objective hierarchy applied by the decision-maker.

7.3.2
Simulation and Scenario Analysis

However, using criteria and indicators only for monitoring, documentation and evaluation does not comply with our aims. In fact, effects of criteria and indicators will not become apparent until they are integrated into the planning and decision-making process. In such long-living systems as forests, long-term effects of the actual management have to be considered.

For this, growth models are the suitable tools; simulation is the target-orientated method. Enterprise simulation enables a planner to test and evaluate different management alternatives (e.g. tending strategies, final cutting rates, changing of tree species composition) and their long-term consequences for estate development. If possible, besides the classical variables of timber production (cf. Table 7.1, criteria 1 and 3), scenario simulations should also contain indicators of further criteria. In this case planning alternatives can be evaluated (simultaneously at stand, stratum or estate level) according to their multi-criteria objective fulfilment. By integrating them into enterprise simulation, SD criteria and indicators – which otherwise would be limited to their controlling and verifying functions – are realised in the planning process.

Figure 7.2 outlines the usage of indicators $[I_1, ..., I_n]$ for strategic planning and decision-making: starting from the initial state of the referring site unit at time t0 (black circles), management alternatives (A, B, C) are simulated [e.g. continuation of the present even-aged forest (A), conversion of pure Norway spruce stands into mixed stands of Norway spruce and common beech (B), increasing cultivation of Douglas fir (C)]. Analysis of these scenarios reveals the consequences of management alternatives in a long-term run. Regarding all criteria in our example scenario, scenario C remains close to the target value, while scenarios A and B are sub-optimal. Scenario simulations are an important prerequisite for a mul-

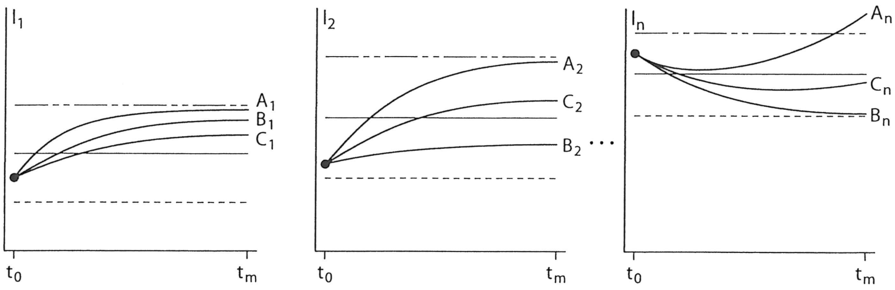

Fig. 7.2. Application of the indicators $[I_1, ..., I_n]$ for strategic forest management. Trajectories A_i, B_i and C_i show the simulated dynamics of $[I_1, ..., I_n]$ in time span $[t_0, t_m]$ as a result of alternative management regimes. *Solid lines* represent the target value of the indicators; *broken lines* show critical levels

ti-criteria evaluation of management alternatives. Analysis of indicator dynamics may replace area-specific, volume-specific or equation-based indicators. With the observed indicators covering a broad range of characteristics and their long-term dynamics, multi-functional SD can be made operational.

7.4
Simulation Models as a Tool for Strategic Planning and Decision-Making of Sustainable Development

The significance of silvicultural growth models and forest growth simulators results from the longevity of trees and stands. Because of the long growth periods covered, recently adopted silvicultural management strategies normally cannot be examined within field trials. The examined silvicultural management strategies would have become obsolete or forgotten before these long-term surveys are completed. Therefore, forest science derives functional relations from experiments and combines them into models of forest development. With those models, it is possible to simulate the system's behaviour in fast motion or "if–then" analyses. Through simulation, ecological, yield-referring and micro-economic consequences of management strategies or natural disturbances can be emulated with the model. Biogeochemical or ecophysiologically based process models outline limits (e.g. constraints in terms of critical inputs and outputs, actions and states) in which forestry can act without putting the stability criteria of the systems to be managed at risk (Fig. 7.3). To fix those constraints, permanent ecological observations, soil surveys and site mappings may contribute. Socio-economic constraints include estate management, protective regulations and forest laws. Once those constraints have been fixed, management models may help identify the optimal stand management for a given initial state and within the predefined corridor. In the example of the growth simulator SILVA which follows, it will be shown how management alternatives may be tested by enterprise simulation for their effects on the total estate, given an initial state and management objective. SILVA

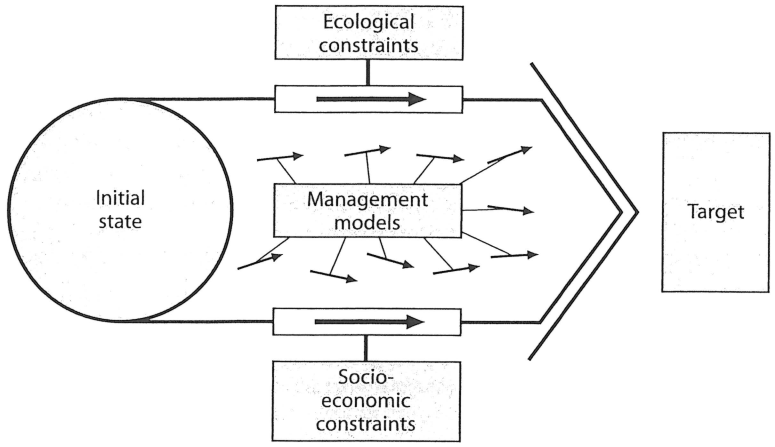

Fig. 7.3. Management models support the decision within a given decision corridor (*framed arrows*) by simulating long-term consequences of management alternatives (*mobile arrows*)

2.2 stands as a proxy of a new model generation which the models BWIN, PROGNAUS and MOSES also belong to (Hasenauer 1994; Sterba et al. 1995; Nagel 1999). Possible applications of SILVA 2.2 extending from tree to state level are exemplified at estate level (Pretzsch et al. 1998; Dursky 2000; Müller 2000). Application and evaluation of the SILVA simulator on other spatial scales are discussed by Knoke (1998), Hanewinkel and Pretzsch (2000) and Duschl (2001). The advantage of these model applications compared with abstract comparisons of alternatives is the consideration of numerous initial states at time to.

Figure 7.4 outlines four steps of strategic enterprise planning and decision-making in which growth models are applied:

1. All stands or sample plots registered by inventories are first assigned to specific strata by cross-classification. Strata may be typical classes of sites/stands or tree species/growth dynamics. With this procedure, a middle course between a rough and therefore less significant stratification and a too fine stratification with a number of strata similar to the number of stands is chosen. Indicator stands are then chosen representing defined strata. Indicator stands serve as the estate's yield classification (e.g. calibration with basic forest inspections) and define management alternatives. By applying a yield-referring growth model, economic and ecological consequences of the alternatives can be analysed. Discussing "if–then" relations of alternative management actions on indicator stands serve as a quantitative basis for objective definitions and objective agreements.
2. Management alternatives developed for indicator stands are assigned to associated strata. Using inventory data, simulation runs are carried out for all strata, highlighting the long-term consequences of the defined management strategies, e.g. for timber production, financial value increment and stability. Among others, global cutting rates are gained for each stratum and the set of chosen management alternatives.

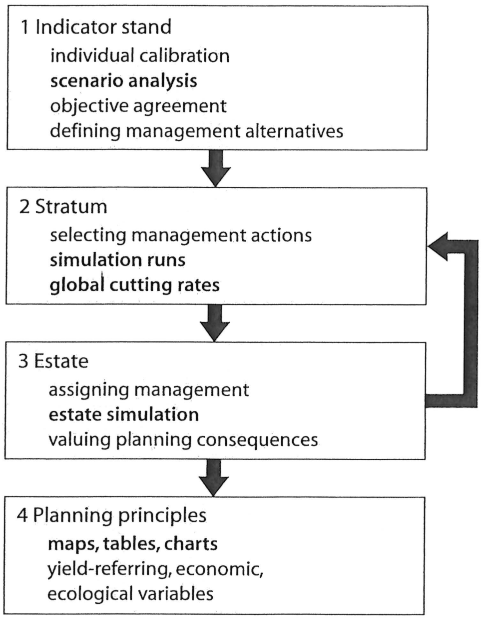

Fig. 7.4. Concept for the application of growth models for strategic planning at estate level. Simulation helps us understand what effect alternative management regimes have on the long-term development of a forest estate

3. After having assigned every inventory plot to a stratum and an appropriate stratum-specific management – or a set of managements – the total enterprise dynamics can be simulated. With this, it is possible to analyse the consequences of stand- or strata-referring management actions on long-term enterprise development. To avoid an undesired development at estate level, management strategies defined for the strata can be modified or combined in a different manner if necessary. With the model aggregating individual decisions from stand or stratum level to estate or higher levels, the advantages of different individual decisions become clearer. Simulation runs over several decades may reveal long-term consequences of chosen management alternatives at estate level, e.g. shortages in liquidity, deficits in specific assortments, etc. One may react to undesired dynamics at estate level by reconsidering or adjusting management strategies at stand or stratum level (feedback arrows in Fig. 7.4). It is exactly this that paves the way for strategic planning and decision-making at estate level.
4. Established management strategies for the defined strata, management-referring yield tables with global cutting rates, and thematic maps showing yield-referring, economic and ecological values of indicator stands – representing strata, stands, inventory plots and the total estate – are fundamental bases for silvicultural management.

Figure 7.5 shows the dynamics of annual volume increment, growing stock, cutting rate and net return from timber sale simulated by SILVA 2.2 within a 30-year period after the 2000 forest inventory in the Municipal Forest of Traunstein.

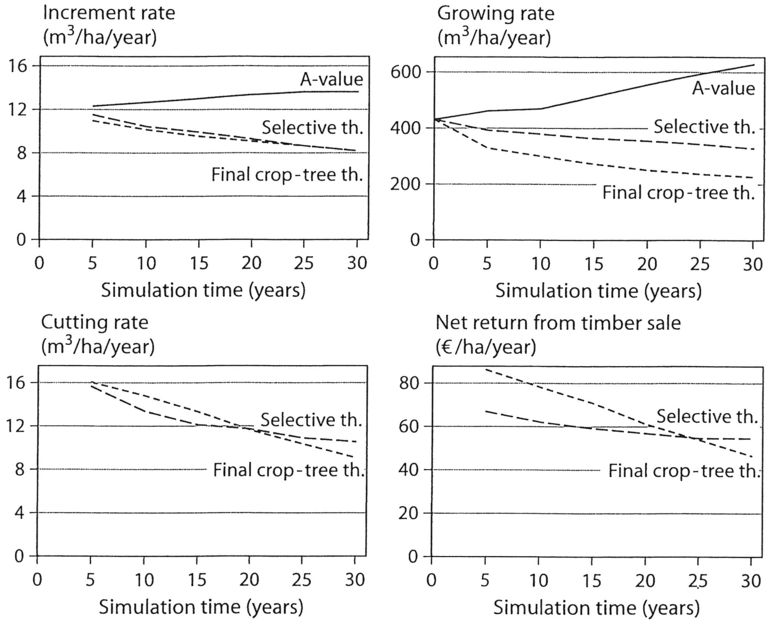

Fig. 7.5. Annual volume increment, growing stock, cutting rate and net return from timber sale for the forest estate Traunstein, southern Germany, simulated with different thinning alternatives applied: (1) A-value based thinning, (2) selective thinning, (3) final crop-tree thinning. Depending on the applied thinning regime, the growing stock stabilises, increases or decreases

With this example, the conceptual considerations discussed in Section 7.3.2 (see Fig. 7.2) are exemplified. The reference shows the dynamics of the A-value-based conditions. The strategy of final crop-tree thinning is superior to selective thinning in cuttings and net return and would lead to a significant growing-stock decrease accounting for 426 m³/ha at present to about half the amount in 30 years. This management strategy would not be compensated by a higher increment, such that a sustainable net return would be put at risk. Selective thinning only would lead to a slight growing-stock decrease and therefore stabilise net return. Similar considerations could also be carried out for all other yield-referring, economic and ecological variables calculated in simulation runs. Only estate-level simulation of that kind reveals the long-term consequences of chosen management alternatives for the forest enterprise.

7.5
Spatially Explicit Modelling and Visualisation of Natural Scenery

Planning decisions, like tree species selection, thinning and regeneration, have impacts on the natural scenery and therefore on protective and recreational func-

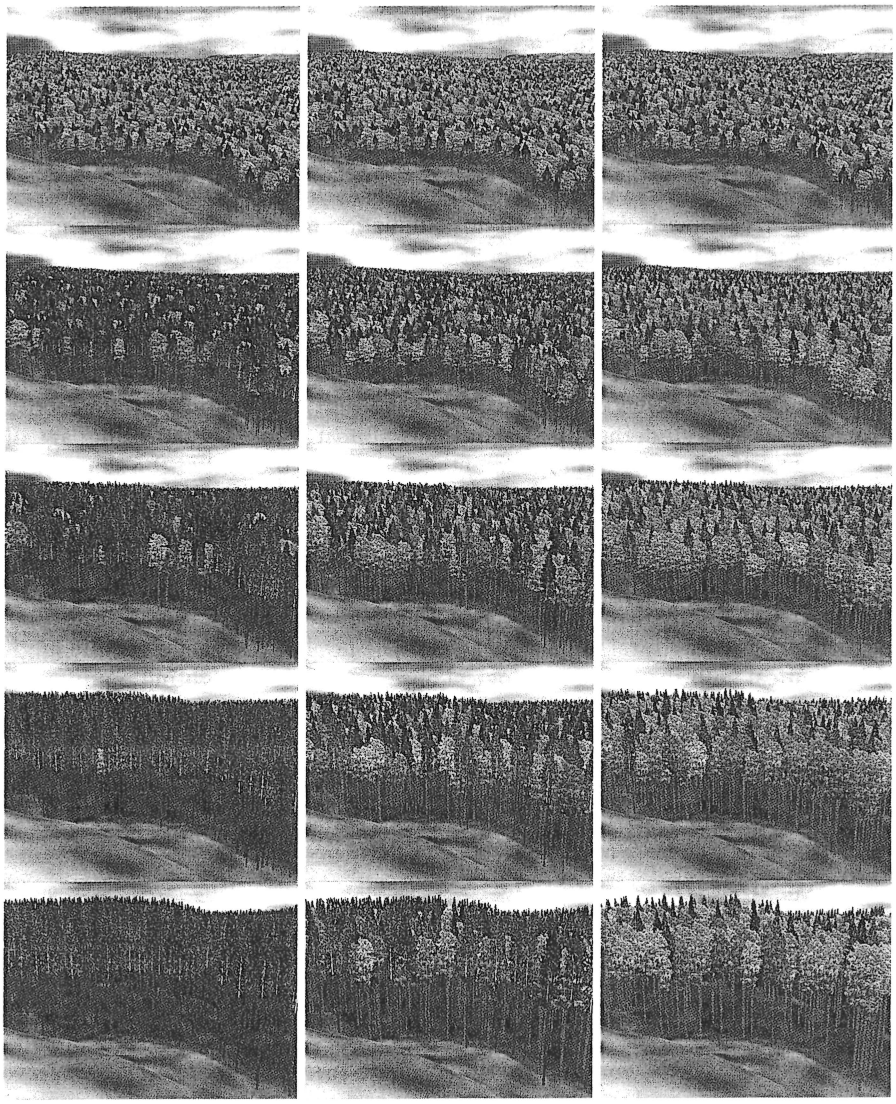

Fig. 7.6. Visualisation at landscape level. Development of Norway spruce/common beech mixed stands in the Traunstein forest estate, Germany, from age 25 to 125 (from *top* to *bottom*). *Left column* Without management; *middle column* thinned from above with moderate promotion of beech; *right column* heavy promotion of beech

tions (cf. Table 7.1, criteria 5 and 6). To support decision-making, appropriate computer programs can be used to visualise the long-term consequences of management alternatives. From available data of landscape relief, surface structure, stand boundaries and stocking type, three-dimensional landscape views are generated, enabling a user to look down from an arbitrary viewpoint. By coupling with an individual-tree-based growth model, static records can be assigned to a dynamic view (Pretzsch and Seifert 2000). This is shown in Fig. 7.6 by a section of the Municipal Forest of Traunstein. The initial situation forms a 25-year-old mixed stand of Norway spruce and common beech. This stand, with an area of about 5 ha, is at first displayed in its present condition by the visualisation program L-VIS (Fig. 7.6, upper row). In a second step, the stand development is simulated with an individual-tree growth simulator. In this simulation example, the growth simulator SILVA is used between the ages of 25 and 125. Three management alternatives are compared for simulation: (1) development without any silvicultural management, (2) moderate promotion of beech by thinning from above, and (3) strong promotion of beech by thinning from above. The results of these alternatives can be visualised (Fig. 7.6, left, middle and right columns, respectively). With no management, a homogeneous pure spruce stand evolves (left column). Without active promotion, beech underlies spruce and fails almost completely until the age of 125 due to self-thinning. With moderate promotion at the end of the simulation, beech's share accounts for 20%; with strong promotion it accounts for 50%.

Visualisation is based on scenario simulations with individual-tree models reproducing tree and stand dynamics spatially. In these types of models the single tree forms the basic informational unit. Its diameter, height, crown base and crown base position are modelled depending on site characteristics, competition, disturbances, silvicultural management, etc. The level of abstraction in the model is identical with the level of biological observation. For weighting up different planning alternatives and for deliberations with stakeholders in silvicultural planning, visualisation may evolve into an effective tool in participative planning and decision-making processes.

7.6
Structural Diversity and Biodiversity

Trees, forest stands and silvicultural landscapes are components between, within or by which physical, biological or ecological processes are running. Stand or landscape structure therefore affects habitat suitability and biodiversity (Fig. 7.7). For example, stand structure determines the abundance and population dynamics of owls, woodpeckers and bears to such an extent that it may serve as an indicator for evaluating habitat quality and managing population dynamics (Letcher et al. 1998; Wiegand 1998). The close relationship between structures of stands and trees and their colonisation by birds, beetles, spiders, lacewings and bugs is pointed out among others by Ellenberg et al. (1985) and Ammer and Schubert (1999). Knowledge concerning relations between structural characteristics and habitat or species diversity is still fragmentary. However, it is commonly agreed that with a rising structural diversity, the diversity of animal and plant species also increases (Haber 1982). Thus, structural characteristics account for easy-to-measure unspecific indicators for potential biodiversity of forest ecosystems (Ulrich 1999). Structural characteristics can be more easily surveyed and inventoried on a larger scale by forest inventories than number, density and diver-

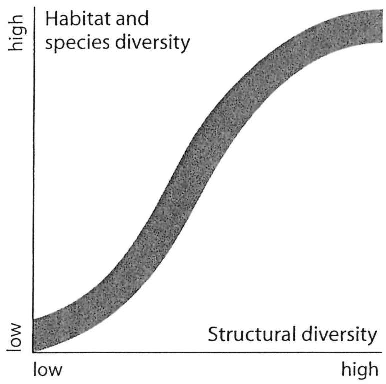

Fig. 7.7. Schematic relationship between structural diversity and species/habitat diversity. (Adapted from Begon et al. 1991)

sity of single animal or plant species themselves. Because of the high measuring costs, these can only be measured selectively, but they strongly correlate with the widely available structural variables. From this point of view, structural values – already known from forest inventories or otherwise easy to measure – serve as indicators monitoring detailed but difficult-to-access information. If structural characteristics are integrated into growth models, they might enter strategic planning (cf. Sect. 7.2.2).

7.6.1
Identifying Structures at Estate Level: the Species Profile Index

As an example, the index A_{rel} is introduced, describing the allocation of the stand space by tree species (Pretzsch 2002). The index may be calculated from inventory data and correlates with the habitat suitability of deer, hollow-nesting birds and deadwood-colonising organisms as well as with recreational functions and aesthetic values (Pott 2002). This index enables the description of a stand's structural state. From repeated measurements, structural changes can be quantified.

The index A_{rel} is based on the index of Shannon (1948). For its calculation a stand is divided into three height layers j=1, 2, 3, representing 0–50, 50–80 and 80–100% of stand maximum height, respectively. By enumeration, the number of individuals of species i in layer j is identified. Summing-up the products of species share and logarithmic species share for i=1 to S species and j=1 to Z height layers results in an index quantifying biodiversity and vertical allocation of species in a forest stand. The maximum index value with given species number S and layers Z is $A_{max}=\ln(S\cdot Z)$. Therefore the index A_{rel}

$$A_{rel} = \frac{-\sum_{i=1}^{S}\sum_{j=1}^{Z} p_{ij} \cdot \ln p_{ij}}{\ln (S \cdot Z)} \cdot 100 \qquad \text{(Eq. 7.1)}$$

denotes how close a given stand structure is to the maximum structuring possible with the given species abundance. Equation (7.1) consists of: (1) S or number of occurring species, (2) number of height layers (Z, in this case three layers), (3) species share in layers (p_{ij})

$$p_{ij} = \frac{\mathrm{n_{i,j}}}{\mathrm{N}},$$

(4) number of individuals of species i in layer j (n_{ij}), and (5) total number of individuals (N). Instead of height layers, diameter classes may also serve as an input to the index. Figure 7.8 shows the species profile index A_{rel} for pure and mixed stands of Norway spruce (*Picea abies* L.) and common beech (*Fagus sylvatica* L.). The index adds up to 100%, ranging from pure spruce stands (A_{rel}=26.5%) to even-aged spruce–beech mixed stands (A_{rel}=79.0%) and uneven-aged spruce–beech mixed stands (A_{rel}=92.1%).

7.6.2
Scale-Comprehensive Indicators

The ln(species number A)-ln(area F) diagram (Fig. 7.9) denotes the efficiency of using sample plot data for describing stand structures giving information regarding the α, β and γ diversity of tree species (Whittaker 1970). This analysis starts with identifying the number of tree species A_1 at an inventory plot with the area F_1. The identification shows the first tuple [$\mathrm{A_1, F_1}$]. Now, around the centre of the inventory plot concentric circles with stepwise increasing radii are set. For each of these circles $k_{1,\ldots,n}$ the number of appearing tree species and the enclosed area may be identified. Species numbers $A_{1,\ldots,n}$ are recorded against the respective circle areas $F_{1,\ldots,n}$ in a double-logarithmic ln(A)-ln(F) diagram (Fig. 7.9). In order to obtain stable information for an observed region, many or all inventory

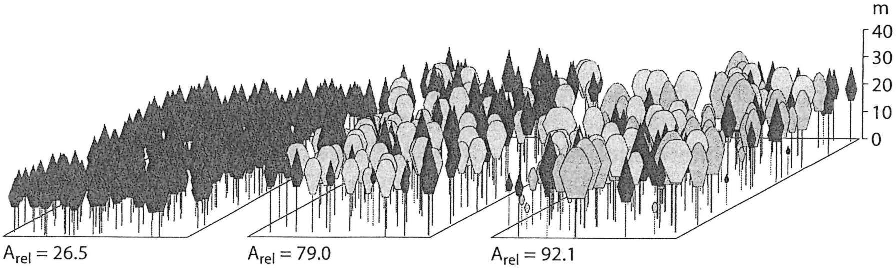

Fig. 7.8. Species profile index A_{rel} applied to a pure Norway spruce stand (*left*), an even-aged mixed stand of Norway spruce and common beech (*middle*) and an uneven-aged mixed stand of spruce and beech (*right*). Structural diversity increases from *left* to *right* with A_{rel}=26.5, 79.0 and 92.1%, respectively

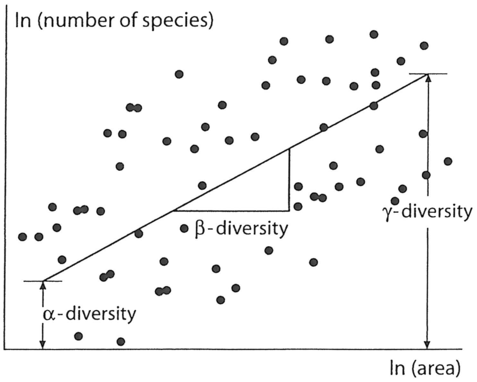

Fig. 7.9. Schematic determination of α, β and γ species diversity. The number of species A based on inventory data is plotted against area F in a double logarithmic grid. ln(A)/ln(F) regression enables diversity quantification from point to regional scale

plots must be analysed repeatedly. The resulting scatter-plot is smoothed by regression analysis with the model

$$\ln A = a + b \cdot \ln F + \varepsilon \qquad \text{(Eq. 7.2)}$$

Parameters a and b denote the information on horizontal characteristics of species numbers within a region. If we are interested in the expected species number in an observed micro-area (α diversity), this can be identified directly from the regression line. Species numbers increasing with increasing areas (β diversity) is represented by the gradient b. To obtain the total number of tree species within a region (γ diversity), its area is applied to Equation (7.2).

The ln(A)-ln(F) line summarises information on horizontal characteristics of biodiversity and forms an indicator for habitat diversity (Rosenzweig 1995). It is appropriate for state description and diagnosis of changes in species composition as well as for characterising and evaluating planning alternatives (monitoring and strategic planning). Species A can be in the form of tree species, soil flora, dead wood, stand gaps, etc.

From simulation runs at estate level, temporal dynamics of ln(A)-ln(F) lines can be derived when comparing different management alternatives. Returning to the simulation run at the landscape level illustrated in Fig. 7.6 with each scenario, ln(A)-ln(F) lines showed the same course at simulation start (t=0). Figure 7.10 schematically illustrates ln(A)-ln(F) lines shifting until time t=100 a. With no action (left), α diversity largely remains unchanged. Because of failing beech and other admixed tree species, β diversity decreases. By keeping with the present management and moderately promoting beech (middle), the ln(A)-ln(F) line only changes slightly. If, however, the enterprise's forests are changed into multi-layered stands promoting beech β diversity and therefore habitat, diversity increases considerably.

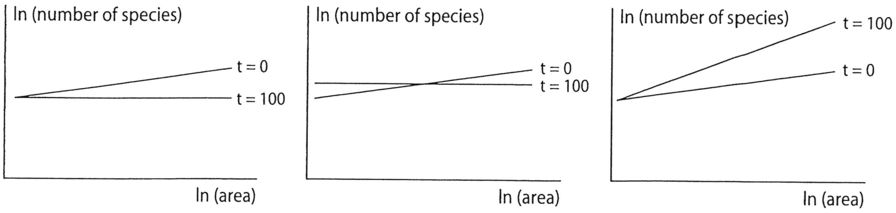

Fig. 7.10. Schematic shift of the ln(A)-ln(F) line affected by alternative thinning concepts. The line t=0 represents the α, β and γ species diversity at the beginning of a 100-year simulation period. Depending on the applied thinning (from *left* to *right*: unmanaged, promotion of deciduous trees, transition to uneven-aged forest) the ln(A)-ln(F) line will shift to the line t=100

7.7
Conclusion and Perspectives

Using SD criteria and indicators for monitoring is different from using them for strategic planning and decision-making. Monitoring claims to define unique and comparable indicators and criteria for a wide range of spatial scales (stand, estate, region, major region) and types of ownerships (state, municipal, private forests). State description and diagnosis of changes require a whole vector of indicators. For this, quantitative indicators and criteria are sought, with which available state data can be best used or which can be measured with an acceptable amount of effort. The temptation to limit data to a few easily measurable indicators is understandable. However, in view of the complexity of forest ecosystems, oversimplified monitoring approaches are not satisfactory when characterising complex forest systems. Key indicators presented by Spellmann (2003) highlight examples for quantitative, scale-comprehensive indicators, which can be generalised and inferred from available data. Suggested indicators have to be analysed regarding their applicability and integrity for monitoring.

As opposed to monitoring, strategic planning will use SD indicators and criteria for fulfilling individually fixed management objectives of an enterprise. Thus, only those criteria and indicators that are relevant for the management objective are selected. Furthermore, selected criteria and indicators are weighed according to the estate's objective hierarchy. In contrast to monitoring, a small number of indicators and criteria will generally be of concern. Weighing the criteria against each other is done by the estate's owner or manager (Sodtke et al. 2004).

The application of simulation models (dynamic growth models) will enable an improved SD evaluation and a more flexible adjustment between singular stand and total estate planning. Simulation models can replace common indicators by aggregated dynamic long-term indicators. Integrating simulation models into the planning process paves the way for strategic forest enterprise planning and SD decision-making – the concept of which is outlined in Fig. 7.11. Simulation models integrated into decision support systems – given initial site, state and management characteristics – may simulate stand by stand or stratum by stratum within batch-mode and can aggregate this partial information for the total

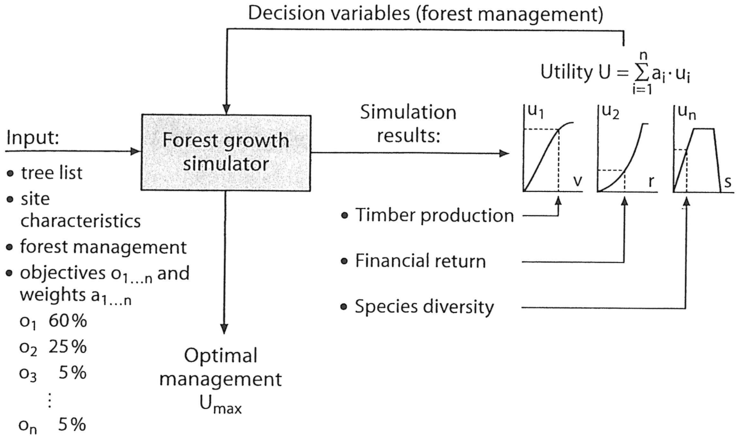

Fig. 7.11. Structure and essential elements of a decision support system for strategic forest management.

estate. Growth simulators can scale at different spatial and temporal levels: from stand or stratum to estate or inter-estate level, from short-term treatment reactions to long-term dynamics. Management alternatives can be analysed regarding their estate-referring and long-term consequences. Silvicultural re-orientation becomes transparent regarding its consequences for the total estate. Concepts and tools for shifting to a multi-functional strategic planning of SD are well developed (Pretzsch et al. 1998; Hanewinkel 2001; Spellmann 2003; von Gadow 2003; Sodtke et al. 2004). Technical equipment such as computers, simulation software, databases and inventory data are available. Their integration into forest planning and decision-making may speed up innovation.

References

Ammer U, Schubert H (1999) Arten-, Prozeß- und Ressourcenschutz vor dem Hintergrund faunistischer Untersuchungen im Kronenraum des Waldes. Forstw Centralbl 118:70–87

Bamberg G, Coenenberg AG (2002) Betriebswirtschaftliche Entscheidungslehre. WiSo-Kurzlehrbücher. Vahlen, München, 328 pp

Begon M, Harper JL, Townsend CR (1991) Ökologie, Individuen, Population, Lebensgemeinschaften. Birkhäuser, Basel, 1024 pp

Bonczek RH, Holsapple CW, Whinston AB (1981) Foundations of decision support systems. Academic Press, New York

Dursky J (2000) Einsatz von Waldwachstumssimulatoren für Bestand, Betrieb und Großregion, Habilitationsschrift an der Forstwissenschaftlichen. Fakultät der Technischen Universität München, Freising-Weihenstephan, 223 pp

Duschl C (2001) Simulation fortbetrieblicher Sachverhalte auf der Basis gegenwärtiger Waldstrukturen. Forstliche Forschungsberichte München, no. 181. Wissenschaftszentrum Weihenstephan für Ernährung, Landnutzung und Umwelt der Technischen Universität

München und Bayerische Landesanstalt für Wald und Forstwirtschaft, Freising, 178 pp

Ellenberg H, von Einem M, Hudeczek H, Lade H-J, Schumacher HU, Schweinhuber M, Wittekindt H (1985) Über Vögel in Wäldern und die Vogelwelt des Sachsenwaldes. Hamb Avifaun Beitr 20:1–50

Haber W (1982) Was erwarten Naturschutz und Landschaftspflege von der Waldwirtschaft? Schriftenr Dtsch Rates Landespflege 40:962–965

Hanewinkel M (2001) Neuausrichtung der Forsteinrichtung als strategisches Managementinstrument. Allg Forst Jagdz 172(11):203–211

Hanewinkel M, Pretzsch H (2000) Modelling the conversion from even-aged stands of Norway spruce (Picea abies L. Karst.) with a distance-dependent growth simulator. For Ecol Manage 134:55–70

Hasenauer H (1994) Ein Einzelbaumwachstumssimulator für ungleichaltrige Kiefern- und Buchen- Fichtenmischbestände. Forstliche Schriftenreihe Universität für Bodenkultur Wien, 152 pp

Hundeshagen JC (1826) Die Forstabschätzung auf neuen, wissenschaftlichen Grundlagen, nebst einer Charakteristik und Vergleichung aller bisher bestandenen Forsttaxations-Methoden. Laupp, Tübingen, 428 pp

Janssen R (1992) Multiobjective decision support for environmental management. Kluwer, Dordrecht, 232 pp

Knoke T (1998) Analyse und Optimierung der Holzproduktion in einem Plenterwald- zur Forstbetriebsplanung in ungleichaltrigen Wäldern. Forstliche Forschungsberichte München, no. 170. Wissenschaftszentrum Weihenstephan für Ernährung, Landnutzung und Umwelt der Technischen Universität München und Bayerische Landesanstalt für Wald und Forstwirtschaft, Freising, 198 pp

Letcher BH, Priddy JA, Walters JR, Crowder LB (1998) An individual-based, spatially-explicit simulation model of the population dynamics of the endangered red-cockaded woodpecker, Picoides borealis. Biol Conserv 86:1–14

MCPFE (1993) Resolution H1: general guidelines for the sustainable management of forests in Europe. In: Proc 2nd Ministerial Conf on the Protection of Forests in Europe, Helsinki, Finland, 5 pp

Müller M (2000) Möglichkeiten und Grenzen des Einsatzes von Waldwachstumssimulatoren für die Betriebsplanung – Untersuchung am Beispiel des Stadtwaldes Traunstein. Diplomarbeit am Lehrstuhl für Waldwachstumskunde der Technischen Universität München, Freising-Weihenstephan, 135 pp

Nagel J (1999) Konzeptionelle Überlegungen zum schrittweisen Aufbau eines waldwachstumskundlichen Simulationssystems für Norddeutschland. Forstl Versuchanstalt 128. Schriften aus der Forstlichen Fakultät der Universität Göttingen und der Niedersächs, Sauerländer, Frankfurt/Main, 122 pp

Pott M (2002) Von Strukturparametern zu Nachhaltigkeitskriterien. Dissertation am Wissenschaftszentrum Weihenstephan für Ernährung, Landnutzung und Umwelt der Technischen Universität München, Freising-Weihenstephan, 115 pp

Pretzsch H (2002) Grundlagen der Waldwachstumsforschung. Blackwell, Berlin, 414 pp

Pretzsch H, Seifert S (2000) Methoden zur Visualisierung des Waldwachstums. Forstwiss Centralbl 119:100–113

Pretzsch H, Kahn M, Dursky J (1998) Stichprobendaten für die Entwicklungsprognose und die Nutzungsplanung. Allg Forstz/Der Wald 25:1552–1558

Rauscher HM (1999) Ecosystem management decision support for federal forests in the United States: a review. For Ecol Manage 114(2/3):173–197

Rosenzweig ML (1995) Species diversity in space and time. Cambridge University Press, Cambridge, 436 pp

Shannon CE (1948) The mathematical theory of communication. In: Shannon CE, Weaver W (eds) The mathematical theory of communication. University of Illinois Press, Urbana, pp 3–91

Sodtke R (2003) Ein Entscheidungsunterstützungssystem für den Zwischenfruchtanbau: Konzeption, Entwicklung, Validierung. PhD Thesis. Christian-Albrechts University, Kiel, 186 pp. http://e-diss.uni-kiel.de/diss_880/index.htm

Sodtke R, Schmidt M, Fabrika M, Nagel J, Dursky J, Pretzsch H (2004) Anwendung und Einsatz von Einzelbaummodellen als Komponenten von entscheidungsunterstützenden Systemen für die strategische Forstbetriebsplanung. Forstarchiv 75(2):51–64

Speidel G (1972) Planung im Forstbetrieb. Parey, Hamburg, 267 pp

Spellmann H (2003) Sicherung einer nachhaltigen Waldentwicklung auf überbetrieblichen Ebenen. Forstwiss Centralbl 122:250–257

Spellmann H, Hillebrand K, Cornelius P (2001) Konzept zur Erfassung und Sicherung der Nachhaltigkeit in multifunktional genutzten Wäldern. Forst Holz 56:469–473

Sterba H, Moser M, Monserud R (1995) Prognaus – ein Waldwachstumssimulator für Rein- und Mischbestände. Österr Forstz 5:19–20

Turban E (1990) Decision support and expert systems. Macmillan, New York

Ulrich B (1999) Entwicklungsprognosen für Waldökosysteme aus der Sicht der Hierarchietätstheorie. Forstw Centralbl 118:118–126

Von Carlowitz HC (1713) Sylvicultura Oekonomica oder Haußwirthliche Nachricht und Naturmäßige Anweisung zur wilden Baum-Zucht. Braun, Leipzig

Von Gadow K (2003) Steuerung und Analyse der Waldentwicklung. Forstwiss Centralbl 122:258–272

Whittaker RH (1970) Communities and ecosystems. Macmillan, London

Wiegand T (1998) Die zeitlich-räumliche Populationsdynamik von Braunbären. Habil Thesis, Ludwig-Maximilians Universität, München, 202 pp

Hubert Hasenauer (Ed.)

Sustainable Forest Management

Growth Models for Europe

With 110 Figures, 30 in color, and 44 Tables

Springer

Prof. Dipl.-Ing. Dr. Hubert Hasenauer
Institute of Forest Growth Research
Department of Forest and Soil Sciences
BOKU University of Natural Resources and Applied Life Sciences
Peter Jordan Str. 82
A-1190 Vienna
Austria

ISBN-10 3-540-26098-6 Springer-Verlag Berlin Heidelberg New York
ISBN-13 978-3-540-26098-1 Springer-Verlag Berlin Heidelberg New York

Library of Congress Control Number: 2005930001

Springer-Verlag is a part of Springer Science+Business Media

springeronline.com

Printed in Germany

Editor: Dr. Dieter Czeschlik, Heidelberg
Desk Editor: Anette Lindqvist, Heidelberg
Production: Pro Edit GmbH, Heidelberg
Typesetting: Satz-Druck-Service, Leimen
Cover desing: Design & Production, Heidelberg

Printed on acid-free paper 31/3152Re 5 4 3 2 1 0

Preface and Acknowledgements

Given the change in silvicultural management from being mainly clear-cut-driven to an uneven-aged mixed small-scale and/or individual tree-driven forest management system, existing yield tables will become increasingly unreliable. As a potential alternative, tree growth models have been developed in order to forecast the growth of each tree within a stand independent of tree age, species mixture and silvicultural management, allowing increased flexibility, which is necessary for modeling such managed forests.

The work presented in this book summarizes a joint effort among European tree growth modeling experts, forest policy decision-makers and forest companies to further enhance modeling theories and to investigate problem-solving methods for silvicultural decision-making. From February 2001 to January 2004, a group of 45 individuals worked within the ITM consortium (Implementing Tree Growth Models for Forest Management), an EU-funded effort to enhance and promote tree growth modeling theories within Europe. For our work, a number of tree growth models were selected. After extending the models and research gaps related to tree growth modeling theory (Chaps. 1–8), the following application examples (Chaps. 9–17) were selected by our company representatives to demonstrate the problem-solving potential:

1. Regeneration in uneven-aged mixed-species stands.
2. Timber-harvesting scenarios.
3. Incorporation of tree growth models in information systems.
4. Using tree growth models beyond the calibration area.
5. Assisting forest policy decision-makers.
6. Tree growth models as a decision support system component.
7. Optimizing cork production in southern Europe.
8. Converting even-aged pure stands into uneven-aged mixed species stands.
9. Modeling coppice forests in Greece.

Many individuals contributed to the success of our work. We are very grateful to our 12 company representatives: Thomas Böckmann, Germany; Miguel Teles Branco, Portugal; Morten Elback Jorgensen, Denmark; Gerhard Fischer, Germany; Josef Gasch, Austria; Stephan Göd, Austria; Ivan Herich, Slovakia; Theod-

oros Kostantinidis, Greece; Jens Briand Petersen, Denmark; Wolf Dieter Radike, Germany; Hermann Spellman, Germany; and Johannes Wohlmacher, Austria – as well as the five members of our quality assurance panel – Marijan Kota, Slovenia; Emilia Pinto Preuhsler, Portugal; Janna Maria Puumalainen; Finland; Konstantin von Teuffel, Germany; and Peter Weinfurter, Austria. Their participation in all the meetings and the fruitful discussions are greatly appreciated.

We also gratefully acknowledge the following colleagues for reviewing one or more of the manuscripts: Ralph L. Amateis, USA; Peter Biber, Germany; Mike Bokalo, Canada; Harold E. Burkhart; USA; Georg Gratzer, Austria; Dionys Hallenbarter, Switzerland; Marc Hanewinkel, Germany; Kevin O'Hara, USA; Jens Haufe, UK; Manfred J. Lexer, Austria; Bruce Michie, Finland; Kelsey Milner, USA; Robert A. Monserud, USA; W. Keith Moser, USA; Arne Pommerening, UK; Philp J. Radtke, USA; H. Michael Rauscher, USA; Keith M. Reynolds, USA; Klemens Schadauer, Austria; Paula Soares, Portugal; Paul Tabusch, UK; Harald Vacik, Austria; Sauli Valkonen, Finland; and Andreas Zingg, Switzerland.

Research efforts such as those presented in this book require funding and professional administration. Thus, we thank the European Commission and our two scientific officers from DG-Research in Brussels, Alexandros Arabatzis and Sjur Baardsen, for their support, as well as the office manger of the ITM program, Roland Berger, who kept everything on track throughout the 3 years of our endeavor to promote tree growth modeling theories in Europe.

Hubert Hasenauer
November 2005

Contents

Chapter 7

Chapter 8

Part II

Demonstrating the Problem-Solving Potential of Tree Growth Models 165

Chapter 9

Chapter 10

Chapter 13